Sustainability in Bio-Energy Production of Poplar and Willow with Respect to Nitrogen Fixation

Georg von Wuehlisch
Institute for Forest Genetics
Grosshansdorf
Germany

- ecology and energy balances of corn a. src
- Nitrogen – useful, detrimental, damaging
- N fixation of poplar and willow
- implications for genetics and clone selection

Sustainability

Hans Carl von Carlowitz, Saxony, Germany
Sylvicultura oeconomica, 1713
“Father of sustainability“

Tab. 8: Rough calculation of net energy yield and output / input ratios, for a wide range of calculable methane yields per ha, respectively selected examples of crops

	Maize	Potatoes	Fodder beet	Oilseed rape	Rye
Methane yield $m^3 . ha^{-1}$	9,886	10,258	9,450	1,442	814
$MJ . ha^{-1}$	353,919	367,236	338,310	51,623	29,141
Process energy demand for digestion	- 53,088	- 55,085	-50,746	- 7,745	- 4,371
Energy requirement in cropping	- 16,800	- 24,200	- 20,350	- 16,800	- 16,800
Total energy requirement	- 69,888	- 79,285	- 71,096	- 24,545	- 21,171
Net energy yield $MJ.ha^{-1}$	284,031	287,951	267,214	27,078	7,970
Output / Input ratio	5.1	4.6	4.8	2.1	1.4

Source: Braun et al. IEA Bioenergy 2009 (under collaboration of vTI)

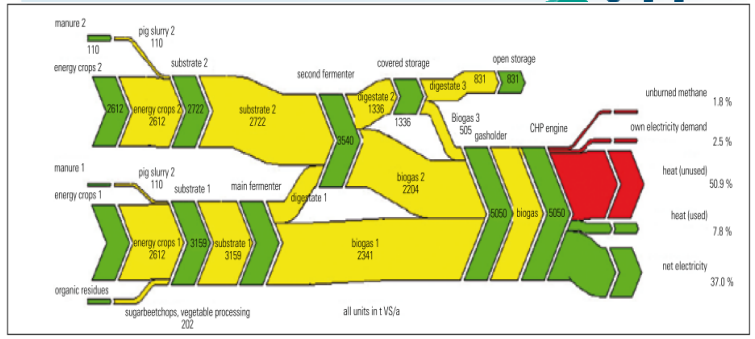


Figure 5: Mass flow and energy efficiency of an energy crop co-digestion plant, showing a net electrical efficiency of 37 % and a high proportion of unused heat (50.9 %). Just 7.8 % of the overall energy can be used as heat. Methane loss in the CHP is 1.8 %. Own electricity demand is 2.5 %.

Source: IEA Bioenergy, Braun et al. 2009

Energy balance: (output : input) = 1.887 (electric)
after Bronner = 1.7

Georg von Wuehlisch, Grosshansdorf

Table 3 – Sensitivity results for different yields scenario

Yield Scenarios ($t\,ha^{-1}$)	Net energy production ($GJ\,ha^{-1}$)	Net energy production with electricity allocation ($GJ\,ha^{-1}$)	Output–input ratio	CO_2 emission ($kg\,ha^{-1}$)	CO_2 emission allocated to electricity ($kg\,ha^{-1}$)	CO_2 emission ($kg\,GJ^{-1}$ net electrical energy)
10 (Base case)	51.6	53.2	19.3	6890	2990	134
8	40.8	42.4	16.1	6890	2980	169
12	62.4	64.1	22.3	6900	2990	111
14	73.0	74.8	23.5	6930	3000	94.9

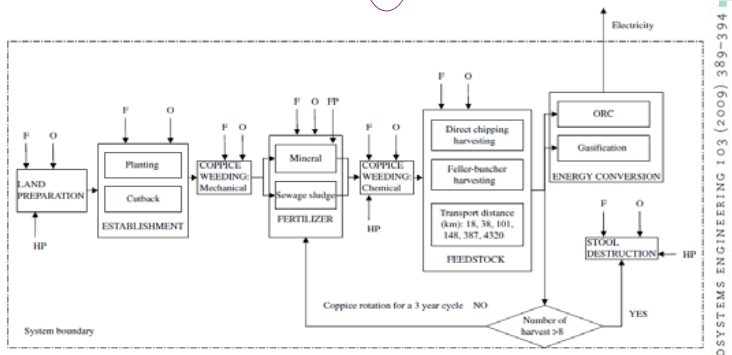


Fig. 1 – System boundaries: F: Fuel consumption, production and transportation; O: Oil consumption, production and transportation; HP: Herbicide production and transportation; FP: Fertilizer production and transportation; ORC: Organic rankine cycle.

BIOSYSTEMS ENGINEERING 103 (2009) 389–394

Johann Heinrich von Thünen-Institut

Nitrogen

necessary – essential for life

valuable - raises yields

noxious – eutrophication, N_2O

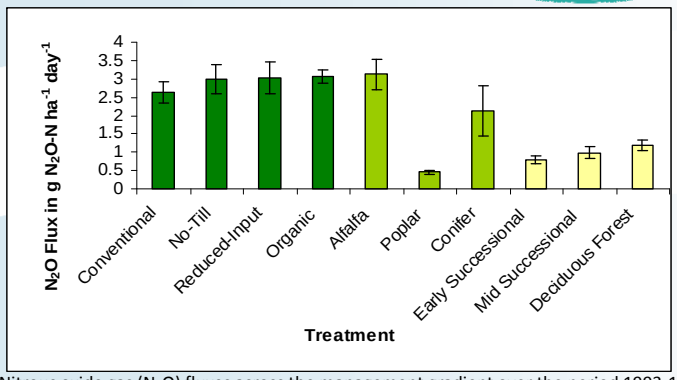
Georg von Wuehlisch, Grosshansdorf

Johann Heinrich von Thünen-Institut

N_2O

- as GHG 298 × more efficient than CO_2
- persists >100 yrs in the atmosphere
- increase of 20 % since industrialisation
- presently 6 % CO_2 equivalents globally

Georg von Wuehlisch, Grosshansdorf



Nitrous oxide gas (N_2O) fluxes across the management gradient over the period 1993-1997 for CF and SF, and 1991-2002 for all other treatments. Bars represent mean fluxes (± se, n=3 or 4 replicate blocks) collected using static flux chambers once in March and twice monthly from April through September, then again once monthly until the ground was frozen.

source: Parr et al. Michigan State University

Nr

- ~ 4 times too much anthropogenic Nr (reactive Nitrogen) is emitted worldwide
- most of this Nr results from synthetic fertilizer
- therefore, plants requiring little or no N- fertilisation should be preferred!

N fertilisation (kg*ha^{-1}) and corn yield (for silage)

Amount for	N	P_2O_5	K_2O
Yield 40 Mg/ha DM	180	70	195
Yield 45 Mg/ha DM	200	80	220
Yield 50 Mg/ha DM	220	90	245
Yield 55 Mg/ha DM	240	100	270

Diazotrophic symbiosis

- in *Fabaceae* diazotrophic *Rhizobia* exist in root nodules
- exchange of NH_3 for ATP from photosynthesis of host takes place in anaerobic cell compartments
- process has been analysed in detail in *Fabaceae*
- legumes are grown widely for N-enrichment in soils

Poplars and willows

- are fast growing even on sites poor in nutrients
- are grown world-wide on ~10 million ha
- have their native habitat on riverbanks poor in N
- react little or not upon N-fertilisation
- have no fertilisation tables or fertilisation recommendations
- show sufficient N in leaves, stem, roots even on poor sites
- don't dispose over root nodules
- many details of N-fixation process are still undisclosed

Georg von Wuehlisch, Grosshansdorf

Natural habitat of poplar on a river bank (*P. nigra*)

Photos: Bioversity, Rome

Scientific proof of N_2-fixation

- other species without root nodules fix N_2 (Prunus a. o.)
- manifold plant growth promoting bacteria reside in p. & w.
- beneficial metabolites (hormones, antibiotics, urea) identified
- vigorous *in vitro*-growth on N-free medium displayed
- *in vitro*-incorportion of rare $^{15}N_2$ into tissue instead of $^{14}N_2$
- evidence of *nifH*-gene of nitrogenase by PCR
- ethylene production in the acetylene reduction assay
- poplar endophyte provoked faster growth in *Poa pratensis*

Georg von Wuehlisch, Grosshansdorf

Verification of N-Fixation in *Salicaceae*

Tree Species	Bacterial strain	Method of Verification	Reference
P. trichocarpa × *P. deltoides*	*Rhizobium tropici*	culture on N-free medium	Doty et al. 2005
[*Populus alba* × (*Populus davidiana* + *Populus simonii*) × *Populus tomentosa*]	*Paenibacillus*	metabolite analysis (urea)	Scherling et al. 2009
P. trichocarpa *Salix sitchensis*	*Burkholderia, Rahnella, Enterobacter, Acinetobacter,*	culture on N-free medium PCR with *nifH* primer acetylene assay	Doty et al. 2009
P. trichocarpa	*Burkholderia vietnamensis*	culture on N-free medium PCR with *nifH* primer acetylene assay $^{15}N_2$ incorporation assay inocula. on other organism	Xin et al. 2009

Advantages from N_2 fixation

- sites poor in nutrients can be utilised for poplar and willow
- highly energy consumptive N-fertiliser is saved
- output vs. input energy balance favourable
- expenditures on fertilizer are reduced
- resources are saved – sustainability is improved
- poplar and willow improve soils by providing N
- High suitability of p. & w. for agroforestry systems
- carbon stocks in soils increases with higher N levels

Georg von Wuehlisch, Grosshansdorf

Implications for tree improvement

- explore interaction between genotype and bacterial community
- analyse the variation in N_2-fixation between genotypes and
- select genotypes for sites, where N is at minimum
- awareness of endophytes offsetting marker assisted selections

Georg von Wuehlisch, Grosshansdorf

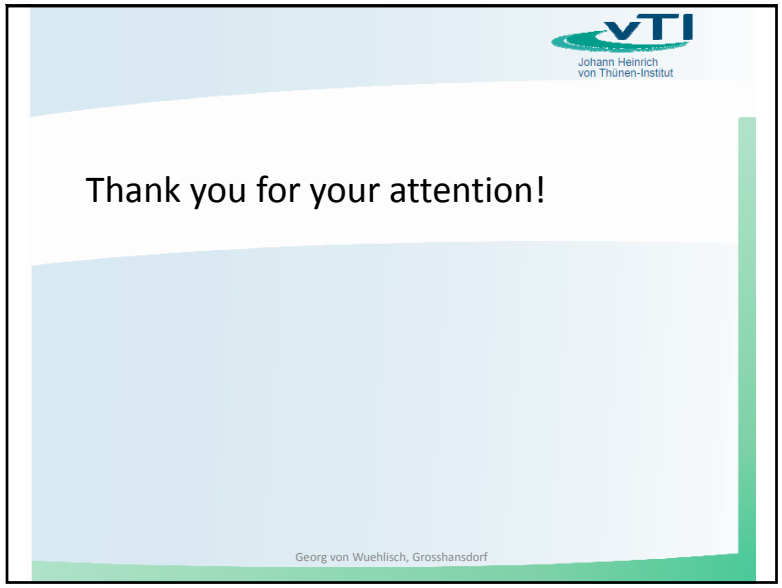
Outlook

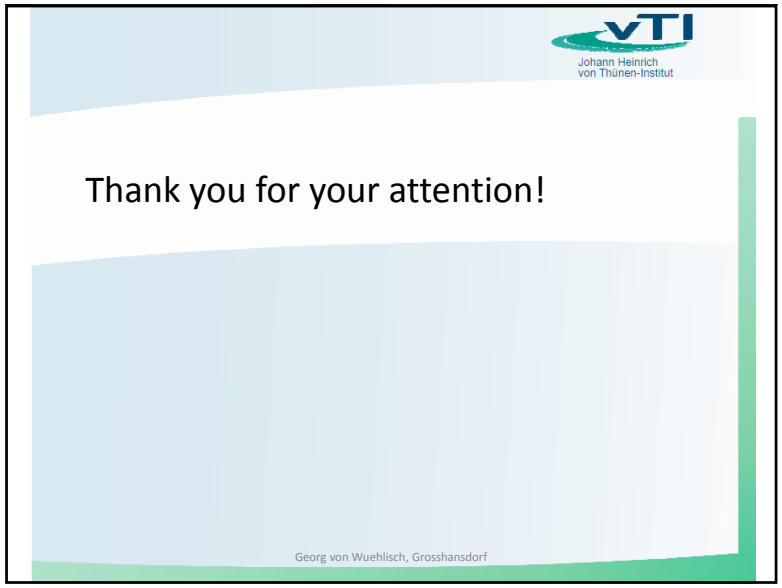
- research to better understand the N_2-fixation process
- minimisation of N-fertilisation needs to be explored
- improvement of soils should be monitored over time
- sustainability of poplar and willow use should be quantified

Georg von Wuehlisch, Grosshansdorf

Thank you!

Georg von Wuehlisch, Grosshansdorf


Johann Heinrich
von Thünen-Institut
Thank you for your attention!
Georg von Wuehlisch, Grosshansdorf


Johann Heinrich
von Thünen-Institut
Thank you for your attention!
Georg von Wuehlisch, Grosshansdorf